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MAN-MACHINE SIMULATION AS A SYSTEM DESIGN AND TRAINING INSTRUMENT

Lawrence T. Alexander

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SYSTEM DEVELOPMENT CORPORATION, SANTA MONICA, CALIFORNIA

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INTRODUCTION

Bioscopic simulation is a research technique which is particularly useful for obtaining human performance data in a complex system environment. This technique can also be used to evaluate prototype configurations of man-machine systems in design stages as well as for training personnel in operating systems. In this paper, I shall describe how bioscopic simulation has been incorporated in the training of a large, information-processing system and how it may be used in system design.

THE SYSTEM BEING TRAINED

The training program to which I referred is the System Training Program (STP), which was developed by the System Development Corporation for the training of the SAGE or Semi-Automatic Ground Environment system of the Air Defense Command.

The SAGE System consists of a network of direction centers, each of which is assigned a sector of responsibility. The direction center (DC) receives information about all aircraft which fly through this sector. This information may come from early warning surveillance sources or from adjacent direction centers; it may be in the form of digitalized radar data or in the form of telephone or teletype messages.

The direction center also receives flight plan information about all aircraft which are scheduled to fly through its sector as well as intelligence data, weather data, and data about the status of various kinds of weapons which it may control.

All this information is processed by a high-speed digital computer and is made available to the operations crew by means of various kinds of console displays. Operators may request specific kinds of information from the computer and can instruct the computer to perform specific kinds of operations by means of switch actions on the consoles. Thus, in SAGE, the operations crew, with the assistance of the computer, maintains surveillance and identifies all aircraft in the air space within its sector of responsibility. If an attack situation develops, the direction center crew takes appropriate tactical action using the weapons under its control.

Air defense sectors are organized into divisions. Air surveillance and tactical information are passed between direction centers of adjacent sectors in order that they may cooperate in meeting an air threat. Over-all coordination of the operations of direction centers is accomplished by the SAGE combat center which is the division headquarters site. The function of the combat center is to process the information received from the direction centers or from adjacent combat centers and to organize it so that the air situation within the division can be analyzed and weapons be properly allocated to meet any hostile threat. Combat Center operations personnel are assisted in these functions by another high-speed digital computer.

SIMULATING THE SYSTEM ENVIRONMENT IN TRAINING EXERCISES

The System Training Program was developed to train the ground crews of the air defense system. In training exercises, the crews use their normal operational equipment. The system interacts dynamically with a simulated defense environment operating in real time. The events which occur in this simulated environment are coordinated in space and time so that the system as a whole can respond to them as it would to similar events in the real environment. These situations can be designed to represent the entire spectrum of environmental conditions which the system might be expected to encounter under a wide range of input loads. Also, by carefully designing the characteristics and rate of the input, and by initiating crisis events, it is possible to control the stress placed upon any system function.

A training exercise may involve a single direction center, an air defense division, or the entire air control and warning net. If a single direction center is being trained, the inputs which it would normally receive from other defense agencies external to it are simulated as well as the air environment.

In training a man-machine system, bioscopic simulation is used in the following manners: 1. To provide situations in which system personnel learn how to utilize their equipment most efficiently, to work together cooperatively, and to implement and adapt system procedures in response to changing conditions; 2. To provide the trainer with human performance data in a realistic system environment in which all variables are effectively operating; 3. To provide the trainer with data by which he can evaluate system output under a wide variety of controlled system input conditions.

Such data are needed for system design also. In the remainder of this paper, I will describe how bioscopic simulation can be used as a system design instrument.

BIOSCOPIC SIMULATION FOR SYSTEM DESIGN

In the Air Defense Command there is a manual backup network for the primary SAGE system. When this manual backup network is used for air defense, the SAGE system is said to be operating under Mode III conditions. The crews which operate the manual system are located at the long-range radar sites from which the SAGE DC obtains its radar information. The problem was to obtain information about the operational capability of various design configurations of the manual system, under Mode III conditions, when it was organized according to the Master Direction Center (MDC) concept of operations.

A master direction center complex characteristically consists of a single master direction center and a number of subordinate sites which report to it. The MDC maintains a vertical board on which is displayed all air traffic within its area of responsibility. It also performs the identification function for the entire complex. A further function conducted at the master direction center is that of weapons assignment and control.

The subordinate sites provide early warning surveillance information and, in some cases, assume tactical control of interceptor aircraft which are assigned to them by the MDC. The MDC complex was organized in this way in order to increase the threat warning time available for action against high-speed targets and to effect a large savings in communication circuitry and personnel while maintaining tactical control of the air battle in a centralized location.

It was expected that the MDC complex would have to operate under severe restrictions of personnel and communications equipment and the problem was how to design the system so as to make maximum use of its limited resources and insure adequate defense capability. Specifically, the following kinds of questions were asked:

1. How many operations personnel are required by an MDC complex in order to insure a stated level of air defense effectiveness, and how should these people be distributed by functions and tasks?

2. Can centralized supervision be effectively maintained at the master direction center? Which supervisory functions must necessarily be performed at the subordinate sites?

3. What are the minimum number of communication channels required among the various sites in the complex, and how should the information load be distributed over these circuits?

4. How much threat warning time can be expected at the MDC, and how complete and accurate would be the air picture displayed there?

A number of design configurations were proposed to answer these questions. It was considered necessary, in order to evaluate their relative worth, to measure the performance output of the operators. In a manual system such as this, humans are involved in evry important information-processing and decision-making function. The effectiveness of the system depends to a large extent upon the efficiency and reliability of the performance of the human components. Consequently, the STP functional simulation technique was utilized to produce high-load input situations which were designed to stress expected weak points in the system.

It was decided that experimental answers to the questions stated above could best be obtained by evaluating the performance of the MDC complex under eight test conditions. These conditions involve (1) use of vertical boards at the subordinate sites; (2) use of communication lines between the subordinate sites; and (3) procedures for forward-telling information from the subordinate sites to the MDC. Two alternative methods of operation were selected for each of these three factors:

1. Use of Vertical Boards at the Subordinate Site. In half of the test conditions, track data were processed in the normal manner, that is, the scope operator told a track to the plotter who plotted it on the vertical board where it was read by a forward teller who passed it to the MDC plotter.

   In the other half of the conditions, the scope reader told tracks directly to the MDC plotter, thus eliminating the plotter and forward teller at the subordinate site.

   The most important consequence of eliminating the vertical board and the two positions required to support it is that information is processed by fewer people. Hence, fewer errors and greater speed are likely. A potential result is that the MDC will have increased threat warning time to take tactical action.

2. Use of Communications Line Between Subordinate Sites. In half of the test conditions, a line between the two subordinate sites was available. In the other half, no line was available.

   Eliminating the line results in a less expensive operation. However, the information which would normally be passed over such a line must then be coordinated by the MDC Surveillance section. This added requirement may result in degraded track continuity in the complex.

3. Forward-Tell Procedures. In half of the test conditions, the subordinate sites were required to forward tell two-minute moves on all traffic until a "cease tell" order was given. In the other half of the conditions, only an initial plot and one two-minute move were required unless the MDC specifically ordered further transmissions.

The latter method was incorporated as a possible way to reduce the load on the forward-tell lines. Two reports are usually sufficient to establish the position, speed, and heading of a flight so that it can be processed by the identification section.

Four test crews were used at each of the experimental sites in the MDC complex. All four crews were exercised once each day for six days in each of the eight test conditions for a total of 192 exercises. The test situations included three wartime and five peacetime STP problems. All were high load problems designed specifically to stress possible weak points in the complex.

Data were collected regarding the time required for the air picture to be displayed on the MDC vertical board. Measures of timeliness, accuracy, and completeness of information were used as criteria for the evaluation of the efficiency of the system under the eight test configurations.

Since it is the purpose of this paper merely to describe a technique whereby man-machine systems may be analyzed, the results of the field experiment will not be presented. However, on the basis of the results obtained, it was possible to arrive at definitive answers to the experimental questions and to provide information on the basis of which we could design the MDC complex for most efficient operation.

By means of the bioscopic simulation technique described, it was possible (1) to obtain measures of the rate of information processing throughout the system, the number and kinds of errors which were made, and a measure of the performance variability of all the operators; (2) to obtain a clear picture of the job requirements at each of the positions throughout the entire complex in terms of the information requirements of the position; (3) to observe performance degradation under various conditions of stress; (4) to determine how centralized supervision from the MDC could be effectively maintained and how restricted communication lines should be used in order to maximize information flow; and (5) to provide an over-all estimate of system efficiency in terms of the primary operational mission of the MDC complex -- namely, how much threat warning time could be expected under various kinds of stress conditions, both in peace and war situations.

<u>SUMMARY</u>

Bioscopic simulation fills a gap in methods for studying man-machine systems which should be exploited further in the future. Bioscopic simulation can provide situations in which the predictions of mathematical and Monte Carlo methods can be tested for consistency, feasibility, and validity. Reciprocally, it can provide needed empirical data on human behavior in systems.

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to train the SAGE system of the Air
Defense Command. Briefly describes
the SAGE system and the training
program developed to train ground
crews of the air defense system.
Describes how bioscopic simulation can
be used as a system design instrument.
Concludes that bioscopic simulation can
provide situations in which the predictions
of mathematical and Monte Carlo methods
can be tested for consistency, feasibility,
and validity. Further concludes that
bioscopic simulation can also provide
empirical data on human behavior in
systems.

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